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Store Separation Testing Techniques at the Arnold Engineering Development Center

Volume IV
Description of Dynamic Drop Store Separation Testing

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ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dynamic drop testing is a method of trajectory simulation whereby store models which are both geometrically and dynamically scaled are released in the wind tunnel air stream and the resulting trajectories are mapped photographically. Drop testing is often used when captive trajectory testing is not feasible or for final trajectory verification prior to flight tests.

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PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the AEDC/DOT. The AEDC project manager was Mr. A. F. Money. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The analysis was conducted under ARO Project Number P32E-39D, and the manuscript was submitted for publication on October 22, 1979.

This report is the last in a series of four volumes of AEDC-TR-79-1 entitled "Store Separation Testing Techniques at the Arnold Engineering Development Center." Subtitles of each of the volumes are as follows:

Volume I	An Overview
Volume II	Description of Captive Trajectory Store Separation Testing in the Aerodynamic Wind Tunnel (4T)
Volume III	Description and Validation of Captive Trajectory Store Separation Testing in the von Kármán Facility
Volume IV	Description of Dynamic Drop Store Separation Testing

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1.0 INTRODUCTION

Dynamic drop, or "free-drop", store separation testing is a method of trajectory data acquisition whereby a scaled model of a store is released in the wind tunnel airflow and the subsequent path of the store is recorded photographically. In addition to being geometrically scaled, the models must be dynamically scaled to represent the mass and moment of inertia characteristics of the full-scale article. Free-drop testing is generally used when the item being tested is to be released from an internal bay, when the expected motion of the store would preclude captive trajectory testing because of sting/aircraft interference (such as an unstable store that would attain high pitch angles upon release), or when the physical size of the test article prohibits the installation of a balance (a rack, for example), or for final store separation verification prior to flight testing. Drop tests have also been conducted utilizing a constrained, pivotal release for fuel tanks and a lanyard-actuated deployment of "pop-out" fins.

The majority of free-drop tests at AEDC have been in the subsonic and transonic speed range and have been conducted in the Aerodynamic Wind Tunnel (4T). Several tests which required larger models than could be accommodated in 4T have been run in the Propulsion Wind Tunnel (16T), using the same techniques as those developed for 4T. Drop tests requiring Mach numbers greater than 2.0 have been run in the Supersonic Wind Tunnel (A). In each tunnel, data acquisition is by use of high-speed, 16-mm cameras. The final trajectory data are obtained by tracking the model trajectory on the film and processing this information with a digital computer which calculates the full-scale positions and angles as a function of time.

This report describes the techniques used in dynamic drop testing at AEDC and details the significant differences between those techniques as applied in the three wind tunnels.

2.0 TEST FACILITIES

2.1 PWT 4-FT TRANSONIC TUNNEL

2.1.1 Description

The Aerodynamic Wind Tunnel (4T) is a closed-loop, continuous flow, variable density tunnel in which the Mach number can be varied from 0.1 to 1.3 and can be set at discrete Mach numbers of 1.6 and 2.0 by the use of fixed-contour nozzle inserts. At all Mach numbers, the stagnation pressure can be varied from 300 to 3,700 psfa. The test section is 4 ft square and 12.5 ft long with perforated, variable porosity (0.5- to 10-percent open) walls.

It is completely enclosed in a plenum chamber from which the air can be evacuated, allowing part of the tunnel airflow to be removed through the perforated walls of the test section. A more complete description of the test facility may be found in Ref. 1.

2.1.2 Aircraft Support Method

For dynamic drop testing, the parent aircraft model is normally supported from the ceiling of the wind tunnel using the base strut of the captive trajectory support (CTS) structure. The CTS strut can be moved vertically and axially in the wind tunnel to allow optimum positioning of the aircraft model in the field of view of the test section data cameras. The aircraft model is mounted by either a sting or a strut which mates to a yoke attached to the CTS strut. Discrete aircraft angles of attack can be set by manually rotating the aircraft support relative to the yoke. At present, it is not possible to vary the angle of attack with flow established in the tunnel. The existing support system positions the aircraft model at a yaw angle of 0 deg. If yaw angles other than 0 deg are desired, they can be obtained by fabricating special adaptors to position the aircraft model at the desired angle.

If required by field-of-view consideration, the aircraft model can be offset laterally. An adaptor to offset the model 8 in. is available. Other offset adaptors could be fabricated as necessary.

A sidewall-mounted reflection plane is also available if the use of half-span models is desired. Use of a half-span aircraft model allows larger scale models to be tested. Various installations are shown in Fig. 1.

2.1.3 Drop Model Recovery

Because of the expense associated with the construction of the dynamically scaled models, a model recovery device is usually installed in the test section. The device consists of two stainless steel, ½-in. mesh screens, one mounted horizontally near the floor of the test section, and one mounted vertically at the entrance to the diffuser. Models will normally be damaged even when they land in the screens; however, they can usually be salvaged and reused with rework (the amount of refurbishment depends on the type of model and the method of construction). Use of the screens does not guarantee recovery of all models. Models which fly over the recovery screens are captured by screens located further down the circuit, but these models generally are damaged beyond repair.

For tunnel operation above $M_\infty = 1.1$, the horizontal catching screen must be removed. Operation at $M_\infty = 1.6$ and 2.0 requires that both horizontal and vertical screens be removed.

2.2 PWT 16-FT TRANSONIC TUNNEL

2.2.1 Description

The Propulsion Wind Tunnel (16T) is a variable density, continuous flow tunnel capable of operation at Mach numbers from 0.2 to 1.6 and stagnation pressures from 120 to 4,000 psfa. The maximum attainable Mach number can vary, depending upon the tunnel pressure ratio requirements, with a particular test installation. The maximum stagnation pressure attainable is a function of Mach number and electrical power. The tunnel stagnation temperature can be varied from about 80 to 160°F depending upon the cooling water temperature. The test section is 16 ft square by 40 ft long with perforated walls of six-percent porosity. The test section can be removed and transported to a separate building for model installation and removal. Two independent test sections, one of which has a permanently mounted sting support system, are available. Additional information about the tunnel, its capabilities, and operating characteristics is presented in Ref. 1.

2.2.2 Aircraft Support Methods

Aircraft models used in previous dynamic drop tests in Tunnel 16T have been strut mounted from the test section ceiling. However, the sting support system mentioned in Section 2.2.1 could be used if required (see Ref. 1). Both the vertical strut ceiling mount and the sting support system have remote pitch capabilities. The angle-of-attack range available is dependent on the test installation. Two installations are shown in Fig. 2.

2.2.3 Drop Model Recovery

The model recovery system in Tunnel 16T consists of two stainless steel screens. A 4- by 8-ft screen is floor mounted on shock absorbers beneath the aircraft model. A vertical screen is placed approximately 6 ft downstream of the horizontal screen to prevent the drop models from being blown downstream into the diffuser. Models recovered from the catching screens can generally be refurbished for reuse. The amount of work required will depend on the type of model and the methods and materials used in its construction. Use of catching screens does not guarantee 100-percent recovery of the drop models. Models which are not captured by the screens will probably be damaged beyond repair in the diffuser or by the compressor protective grid.

Installation of the screens will reduce the maximum Mach number attainable to approximately $M_\infty = 1.4$ and will increase power requirements by about 20 percent (depending on test conditions).

2.3 VKF TUNNEL A

2.3.1 Description

The Supersonic Wind Tunnel (A) is a continuous flow, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel can be operated at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and a stagnation temperature up to 750°R at Mach number 6. The minimum operating pressure ranges from about one-tenth to one-twentieth of the maximum at each Mach number. The tunnel is equipped with a model injection system which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel and airflow calibration information may be found in Ref. 2.

2.3.2 Aircraft Support Method

In Tunnel A, the aircraft model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank, and the safety door seals the tunnel from the tank area. After the aircraft model and store are prepared for a drop, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream. After the drop is completed, the aircraft model is retracted into the tank and the sequence is reversed, with the tank being vented to atmosphere to allow access to the model in preparation for the next drop. The sequence is repeated for each drop. A tunnel installation is shown in Fig. 3.

2.3.3 Drop Model Recovery

A model recovery screen can be installed in the installation tank below the opening for the safety and fairing doors. Some of the models fall to this screen, and others are swept down the tunnel. In both cases, the models are usually damaged beyond repair by the impact.

3.0 DATA ACQUISITION

3.1 GENERAL

Primary data are acquired by means of 16-mm, high-speed motion picture cameras mounted to give both side and bottom views of the model in the test section. The actual frame rates of the data cameras can be varied as required by the particular test program. The data cameras are positioned in such a manner that the relative positions of their lines of sight in the test section are accurately known. By using two orthogonally positioned cameras, three-dimensional, six-degree-of-freedom trajectory data can be determined.

Two different methods are used to provide qualitative film data of a trajectory within a short period of time after a drop has been made. These types of film data, called "quick-look" data, are generally available within one to 15 minutes after a drop has been completed. In Tunnel A, a Polaroid® camera with a rotating shutter is mounted outside the test section. This camera gives a multiple-image photographic record of the drop. Because Tunnel 4T and Tunnel 16T test sections are enclosed in plenums which are at tunnel static pressure, the use of a Polaroid camera is not feasible. Instead, an additional 16-mm, high-speed motion picture camera, loaded with black and white film, is mounted so as to give the desired view of the model. After a drop, the film is developed with a portable processor located in the wind tunnel building.

Data acquisition is controlled by a sequencer which is programmed to automatically actuate the test section lighting and cameras and to release the drop store at the proper time intervals. To allow the time of store release and the camera frame rates to be accurately determined, timing lines and an event mark signifying store release are optically placed on the data film of all data cameras.

3.2 CAMERA INSTALLATION IN THE PWT 4T

In Tunnel 4T, the primary data cameras are installed at tunnel station 108.8 such that the sight lines intersect orthogonally at, and with, the tunnel centerline. The cameras normally are fitted with 5.7-mm lenses. However, 10-mm lenses are available if a larger film image would be useful and the field-of-view requirements can be reduced. A listing of the field of view at the tunnel centerline for both the 5.7- and 10-mm lenses is shown in Fig. 4.

The quick-look camera is installed outside the tunnel side wall at station 97. It can be fitted with various lenses as dictated by field-of-view and image size requirements. Frame rates from 300 to 1,000 per second can be set.

3.3 CAMERA INSTALLATION IN THE PWT 16T

In Tunnel 16T, the primary data cameras are normally installed at tunnel station 9.4. If a ceiling strut mount is used for the aircraft model, the cameras can be mounted at tunnel station 20 although this position may be further downstream than is desirable. Various data camera positions are available in Tunnel 16T, but with the available camera ports only one of the two data cameras can be mounted so that its sight line falls on the tunnel centerline. Regardless of their locations, the data cameras will be mounted so that the sight lines intersect orthogonally. However, the position of the sight line intersection in the test section will depend on the camera location that is chosen. Either 5.9- or 10-mm lenses are available for the Tunnel 16T data cameras. The appropriate lens will be determined by specific test requirements. A listing of the fields of view at the tunnel centerline is included in Fig. 4.

The quick-look camera can be located at several locations as indicated by field-of-view requirements. Lenses ranging from 13 to 50 mm are available for this camera. Frame rates from 300 to 1,000 per second can be set.

3.4 CAMERA INSTALLATION IN VKF TUNNEL A

In Tunnel A, the primary test data are obtained using three 16-mm, high-speed motion picture cameras. The side view is a black and white Schliern photograph taken with the Tunnel A schlieren system. This camera runs at approximately 800 frames per second. The other two cameras are installed on the model injection system such that, when the model is injected into position in the wind tunnel, the cameras are just below the tunnel floor and are aimed through a 7.37-in.-wide slot in the floor. Both cameras use color film and run at a nominal frame rate of 400 frames per second. The camera at the forward end of the slot uses a 50-mm lens and photographs a closeup view of the aircraft; the camera at the aft end of the slot uses a 25-mm lens and is positioned so that its field of view covers a vertical separation distance of approximately 18.5 in. at a longitudinal separation of zero. The fields of view of the various cameras at the tunnel centerline are included in Fig. 4.

Quick-look photographic data are provided by a 4- by 5-in. still camera using a Polaroid film pack and a rotating disk shutter. This camera is set up on the side of the tunnel below the schlieren light path. Multiple exposures are made on the Polaroid film by rotating the disk shutter at a rate of 40 exposures per second.

4.0 DATA REDUCTION

4.1 GENERAL

Model trajectory data are determined from the time-correlated, high-speed motion picture film taken by the two primary data cameras. The data film is reduced by the use of a film reader whereby each frame of the film is projected onto a screen. Positions of the store reference points, relative to known points in the field of view, are measured along two orthogonal axes by manually positioning horizontal and vertical crosshairs located on the surface of the screen. Digital output from the film reader is input to a computer which calculates the full-scale trajectory positions and attitudes.

4.2 DATA SYNCHRONIZATION

If accurate three-dimensional trajectories are to be obtained, the information acquired from the side and bottom data cameras (which may be running at different speeds) must be synchronized. This will insure that the dropped store occupies the same position in space when data from the two cameras are correlated by the data reduction program. At AEDC, this synchronization is accomplished in the data reduction program. The frame rate for each camera is determined from the timing marks recorded on one edge of the film (see Fig. 5). The event mark which is recorded on the other edge of the film in each camera establishes a time zero reference by identifying the frame of film on which store release occurs. The zero reference and the frame rate are used to calculate the elapsed time since release for each frame of data film for each camera. The side camera data are taken as the primary time reference, and the bottom camera data are interpolated to obtain store positions at times correpsonding to each frame of the side camera data.

4.3 DATA REDUCTION IN PWT TUNNELS 4T AND 16T

Calculation of the trajectories is accomplished by the simultaneous solution of the equations which relate any point in the camera field of view to the two orthogonal sight lines of the data cameras. Location of the sight lines relative to a known point on the film (a sprocket hole) and a scaling factor (called the apparent focal length) which relates the film reader image to the full-size model in the tunnel are determined prior to the test by means of a calibration using a grid board. The three-dimensional location of any point in the field of view can then be determined using the method of similar triangles.

For complete six-degree-of-freedom trajectory data, the location of three reference points on the drop store must be determined in each frame of film. These reference points normally consist of one point at the store nose, one point at the tail, and a point laterally offset from the line joining the nose and tail reference points (see Fig. 6). The locations of these three points in conjunction with that of the store center of gravity relative to the nose reference point are used to define the angular and translational position of the store by means of standard geometric relationships. The model-scale data are then converted to the equivalent full-scale values by means of the appropriate scaling factors.

4.4 VKF TUNNEL A DATA REDUCTION PROGRAM

Model trajectory parameters are obtained from the high-speed, time-correlated motion picture cameras located in the schlieren system and at the aft end of the slot in the tunnel floor. To obtain the trajectory data from the film, grids are photographed by each camera. The schlieren camera uses a 6-in. grid which is attached to the tunnel windows and appears on the data film. For the bottom data camera, a 2-in. grid is installed at a known location in the tunnel and is photographed prior to testing. This grid is superimposed on the data film by the film reader during the data reduction process. The location of the store cg and the angle of the store relative to the grid lines are determined from the data film by the film reader. This information is then input to a digital computer which calculates the full-scale displacements and angles as a function of time.

4.5 DATA OUTPUT

Standard data output consists of the full-scale translational and angular positions of the store with time in the flight- and pylon-axis systems. [Angular data can be presented in both the Euler sequence (yaw, pitch, roll) and the pitch, yaw, roll sequence.] In addition, the nose and tail coordinates of the store are calculated as a function of time. Samples of the tabulator formats are presented in Table I. The parameters shown are identified in the Nomenclature. The above data can also be made available on magnetic tape and in plotted form.

The time required for reducing trajectory data varies with the number of drops in a given test. However, unchecked data are generally available within two to three weeks. A print of the color data film is normally available within four days after each drop.

5.0 MODEL-SCALING METHODS

The three primary methods used in scaling dynamic drop store models are Froude scaling, heavy scaling, and light scaling. A complete description of these scaling laws, including the applicable equations and the relative advantages and disadvantages of each, is included in Volume 1 of this series of reports (Ref. 3).

Although no one method of model scaling is necessarily the best method, the majority of drop tests at AEDC have used the heavy scaling technique. Heavy scaling has given good overall results in comparison with captive trajectory and flight test data. However, depending on the test objectives, Froude scaling or light scaling might be preferable, and suitable model design and data reduction can be provided for any of the scaling methods.

6.0 STORE RELEASE AND EJECTOR MECHANISMS

Drop testing requires a reliable and repeatable means of releasing the store on command. It also requires a method of applying an ejector force of sufficient magnitude at the correct point on the store model to impart the necessary initial linear and angular velocities.

Two techniques are presently in use at AEDC. One method uses a high-current electrical discharge to actuate a device called a "burn bolt". The burn bolt is a small machine screw which has had a short section machined to a 0.030-in. diameter. When store release is commanded, a current of approximately 1,200 amps instantly vaporizes the turned-down portion of the screw. The screw can either release the store directly or can actuate a hook mechanism which releases the store (see Fig. 7).

A method recently developed at AEDC uses air pressure to actuate a hook release mechanism. This technique avoids the problems associated with high current circuits (proper grounding, arc over, etc.). Use of the air-actuated release mechanism is restricted to weapons bay drops or pylons because of physical size constraints (Fig. 7). Releases from racks still require the use of the burn bolt system.

Application of model ejector forces is accomplished by the use of springs or air cylinders. Leaf springs, coil springs, and air pistons have all been used with good results. Air pistons have an advantage in that the ejector force can be easily changed during testing. Because of their larger size, the pistons are usually limited to use in weapons bay drops. Both leaf and coil spring ejection systems can be fitted into racks and pylons. However, they require more time than the air pistons to calibrate or to change during testing.

Most aircraft carriage systems now use dual ejector pistons in the pylons to obtain adequate impulse for store separation. In a scaled model, these dual pistons can be simulated with a single ejector piston which provides the required force and moment by applying the force at a single, selected point. The correct model scale ejector forces and moments can also be produced by using two ejectors spaced on the equivalent model scale centers as are the full-scale ejectors. Because of the difficulty in simulating the complete range of full-scale ejector parameters with a single ejector piston, the AEDC air-actuated release mechanism uses two ejector pistons.

Since the model scale ejector forces are determined by the same scaling laws used to determine the model mass and inertia properties, it may be difficult to provide sufficient force with the model scale ejectors. Therefore, the ejection requirements should be considered during the initial stages of drop model design to assure proper simulation.

7.0 DROP MODEL CHARACTERISTICS

Although the desired model scale mass and moment-of-inertia properties are determined by the scaling laws used in their design, the actual model characteristics will vary somewhat from this ideal because of precision limitations in the fabrication process and because of design tradeoffs to limit model costs. For example, it has been found that allowing model center of gravity location to deviate by up to 3 percent of model length and moment of inertia to vary by up to 6 percent from the ideal value will result in a significant reduction in design time without adversly affecting the trajectory motion. However, it is necessary that the actual model characteristics be measured prior to testing to provide a means for proper evaluation of the test data and to determine the accuracy of the simulation.

Model center of gravity location relative to some easily defined position must be determined in the XB, YB, and ZB planes. Store moment of inertia about the actual center of gravity should also be measured. Model mass and inertia properties should be determined after the models have been painted and any desired markings placed on the store. Models are generally painted to enhance their visibility on film. Experience has shown that a nonglossy yellow model with a light blue or gray background gives the best contrast. The AEDC has the necessary equipment to determine the center of gravity and the inertia properties of drop models. Photographs of this equipment are presented in Fig. 8.

Model ejector calibrations are required to determine the necessary springs or air pressure and the point(s) of application of the ejector which give the desired initial vertical and angular velocities to the store. Calibrations are generally made using a time/distance correlation to determine the velocity imparted by the ejectors. Several methods for obtaining the necessary information exist. Both motion picture film of the release and a photo diode array which gives a time history of the drop have been used. A stroboscopic technique presently is being used at AEDC which gives a multiple image on Polaroid film. The necessary measurements are made directly from the film. The angular and linear velocities imparted by a given ejector can be determined quickly after the drop. Any necessary adjustments to the ejector(s) can then be made and new measurements taken within a very short period of time.

8.0 INFORMATION REQUIRED FOR CONDUCTING DYNAMIC DROP TESTING AT AEDC

The following information is needed for each store prior to test entry.

Full-Scale Parameters

1. Store weight, lb
2. Store moments of inertia about the body axes, slug-ft^2
3. Store center-of-gravity location, ft
4. Store forward lug location, ft
5. Ejector force (for each piston if more than one), lb
6. Store linear and angular ejection velocities, ft/sec and deg/sec
7. Ejector stroke length, in. (for each piston)

Model-Scale Parameters

1. Store weight, lb
2. Store moments of inertia, lb-in.^{2}
3. Store center-of-gravity location, in.
4. Store attachment point location, in.
5. Store dimensions, in.
6. Store linear and angular ejection velocities, ft/sec and deg/sec
7. Ejector stroke length, in. (for each piston)

Test Parameters

1. Mach number
2. Release altitude
3. Tunnel dynamic pressure

Other items of information needed prior to testing are:

1. Scale factor
2. Scaling law(s) used
3. Desired data output
4. Type of ejector used
5. Any unusual hardware or test requirements (e.g., pivot releases, installed balance, etc.)

As mentioned in the previous section, the AEDC has the capability to measure the necessary model mass and inertia properties. Model design and selection of test parameters to simulate specific flight conditions can also be accomplished.

9.0 SUMMARY

Dynamic drop testing provides a very valuable tool in the determination of store separation characteristics and for final verification of the store trajectory prior to flight testing. It is especially useful for weapons bay releases, for releases in which the store model motion and/or mounting requirements would result in interference between the store model or its mount and the aircraft model, and for configurations in which balance mounting is impractical.

The AEDC continuous flow, closed-circuit wind tunnels provide a testing capability at Mach numbers from 0.2 to 6.0 over a wide range of simulated altitudes. In addition, the availability of the 16-ft-square transonic test section gives great latitude in the choice of model scale when testing is conducted in the subsonic and transonic ranges.

The AEDC has the capability to plan and conduct a complete drop test program. The expertise of AEDC personnel in dynamic drop testing includes model design, construction, and calibration as well as testing, data reduction, and data analysis.

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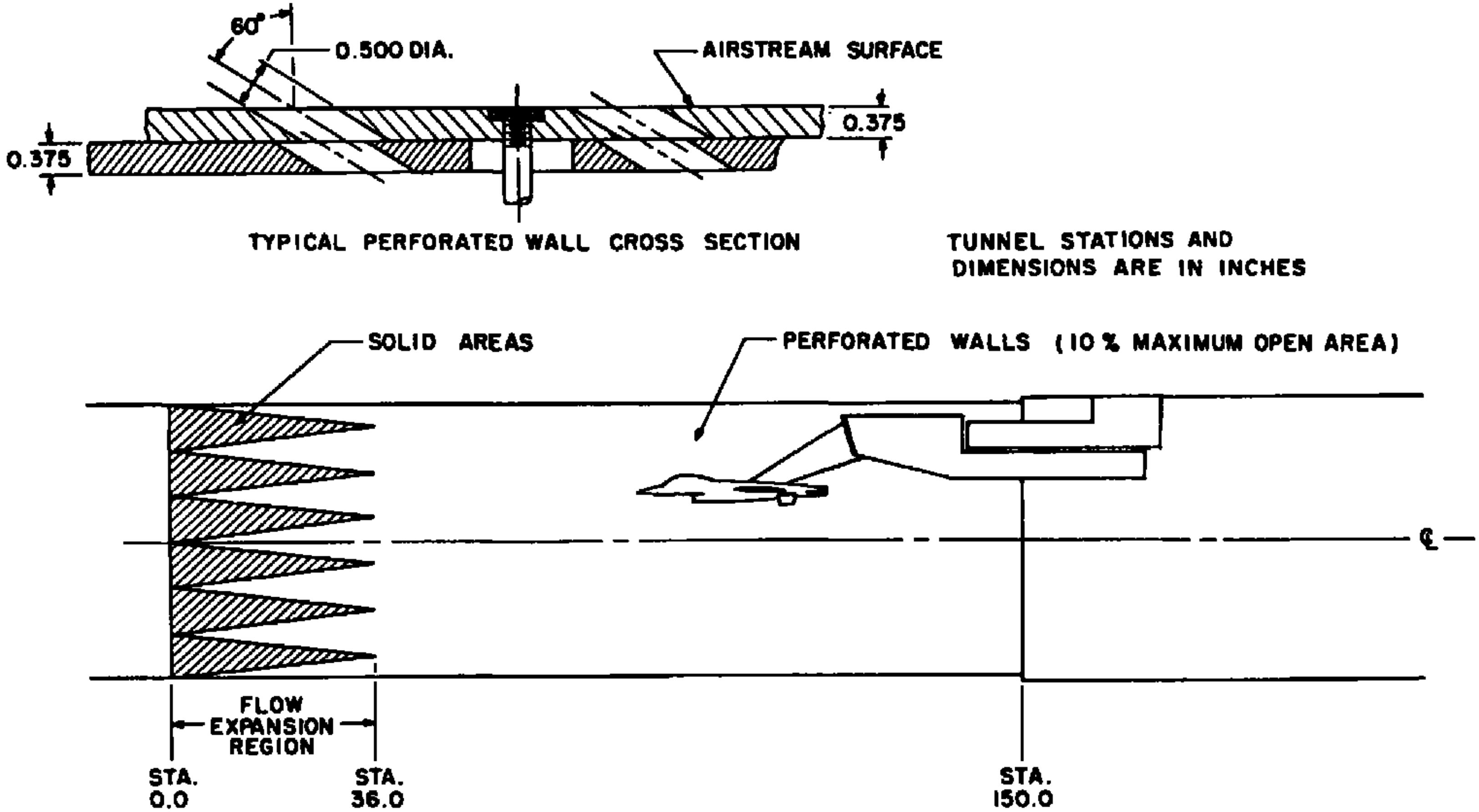
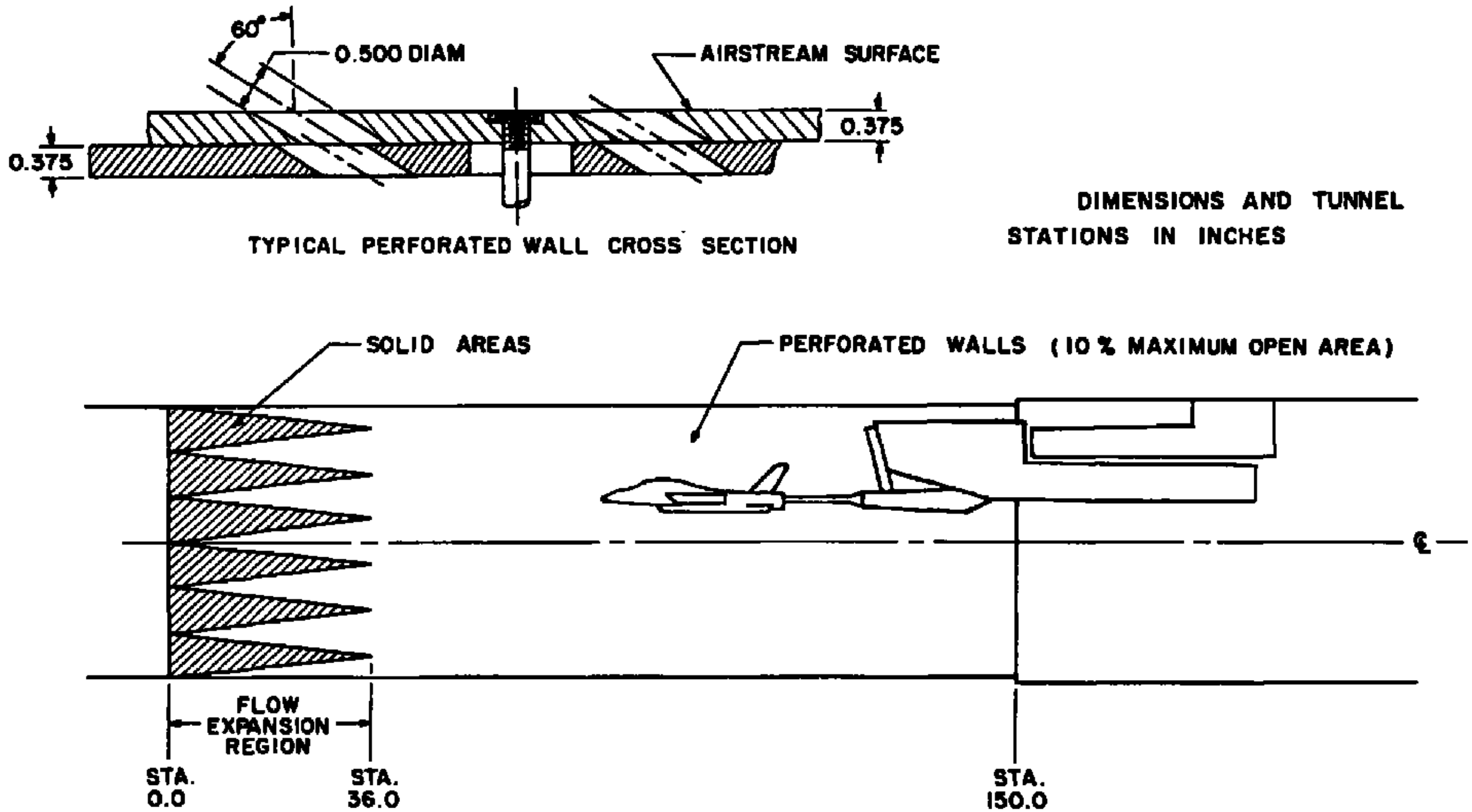
2. *Test Facilities Handbook* (Eleventh Edition). "von Kármán Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, June 1979.

3. Carman, Jack B. "Store Separation Testing Techniques at the Arnold Engineering Development Center, Volume I: An Overview." AEDC-TR-79-1, to be published.

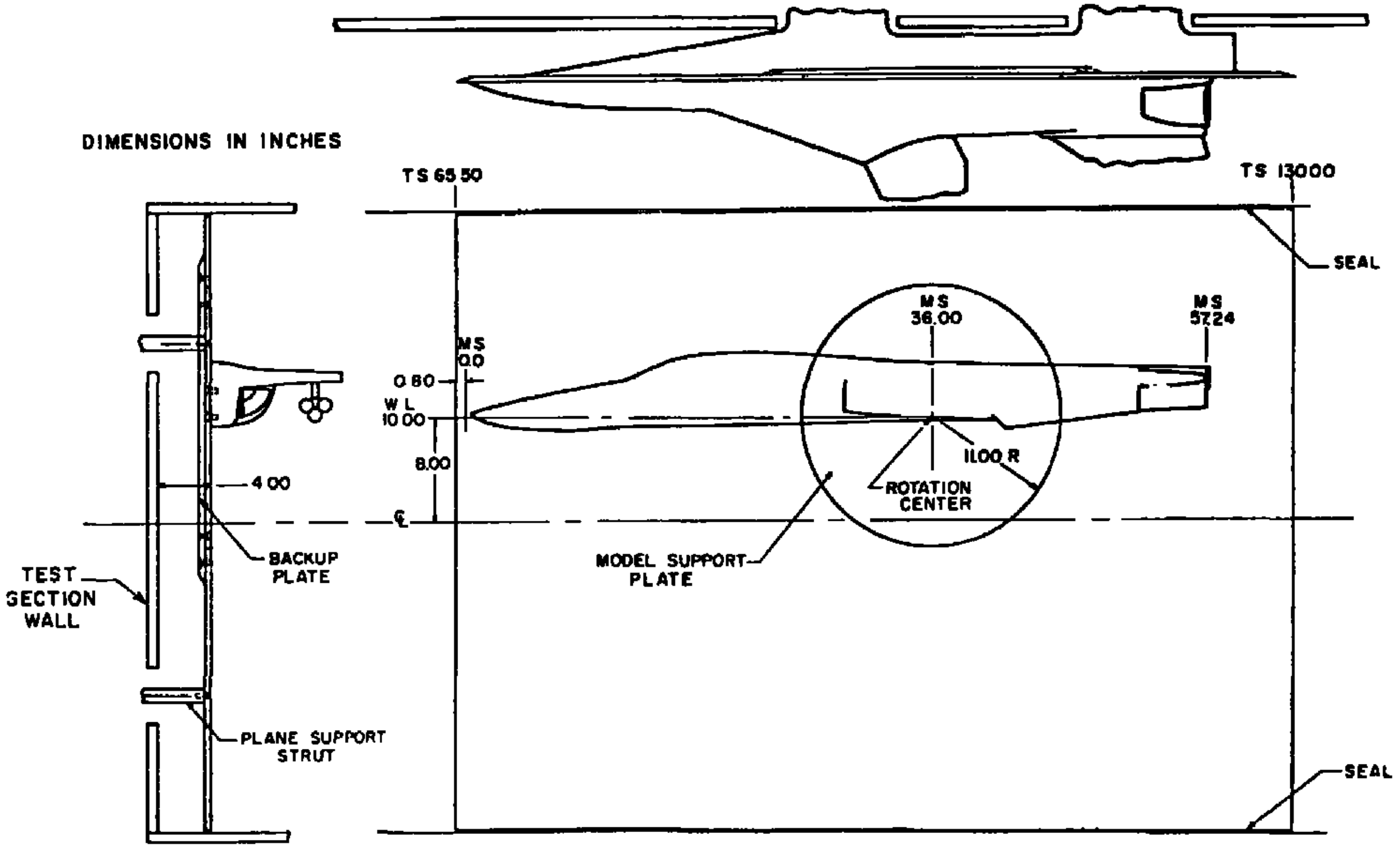


a. Strut mount

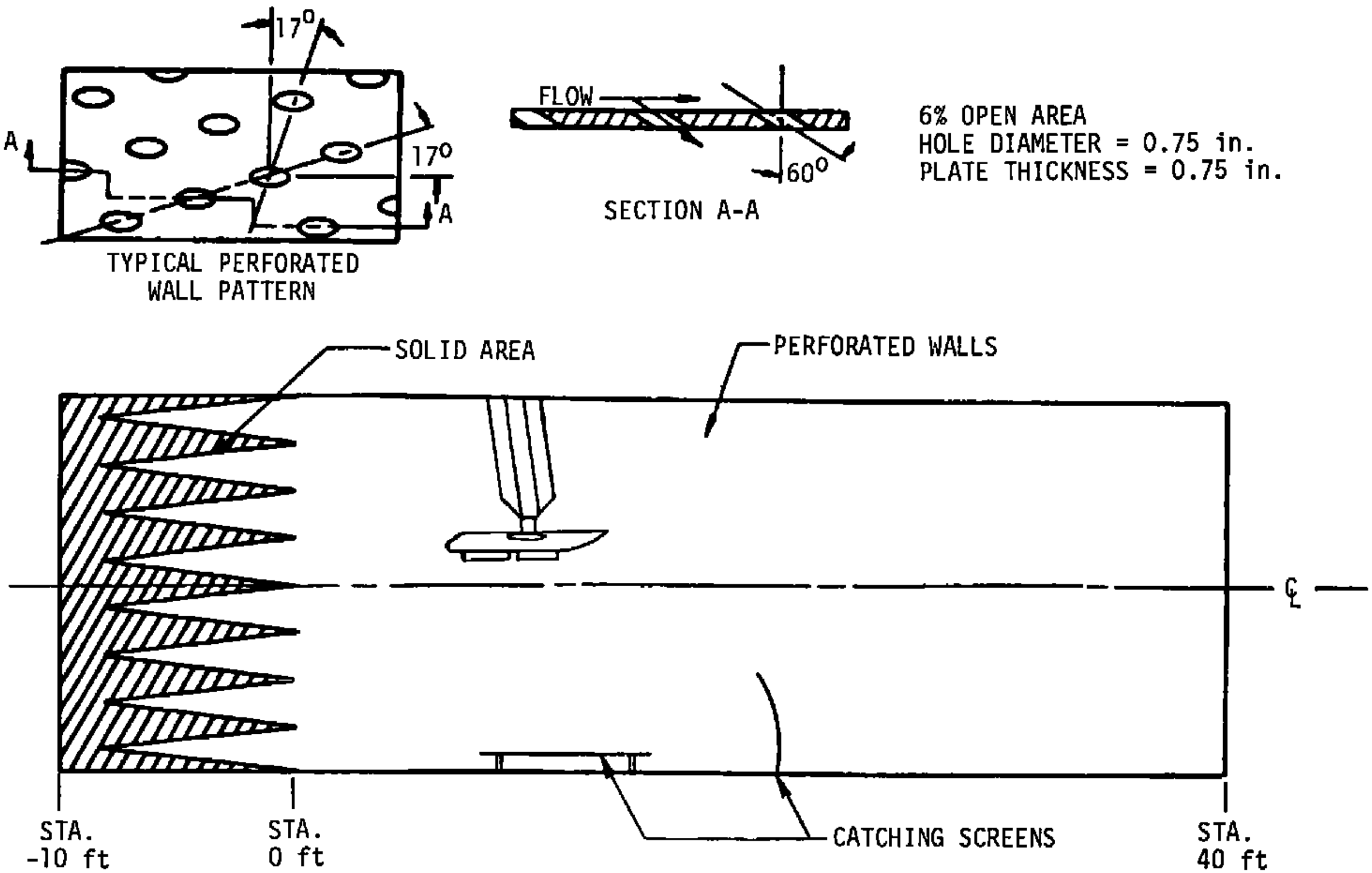
Figure 1. Typical Tunnel 4T dynamic drop test installations.



b. Sting mount
Figure 1. Continued.

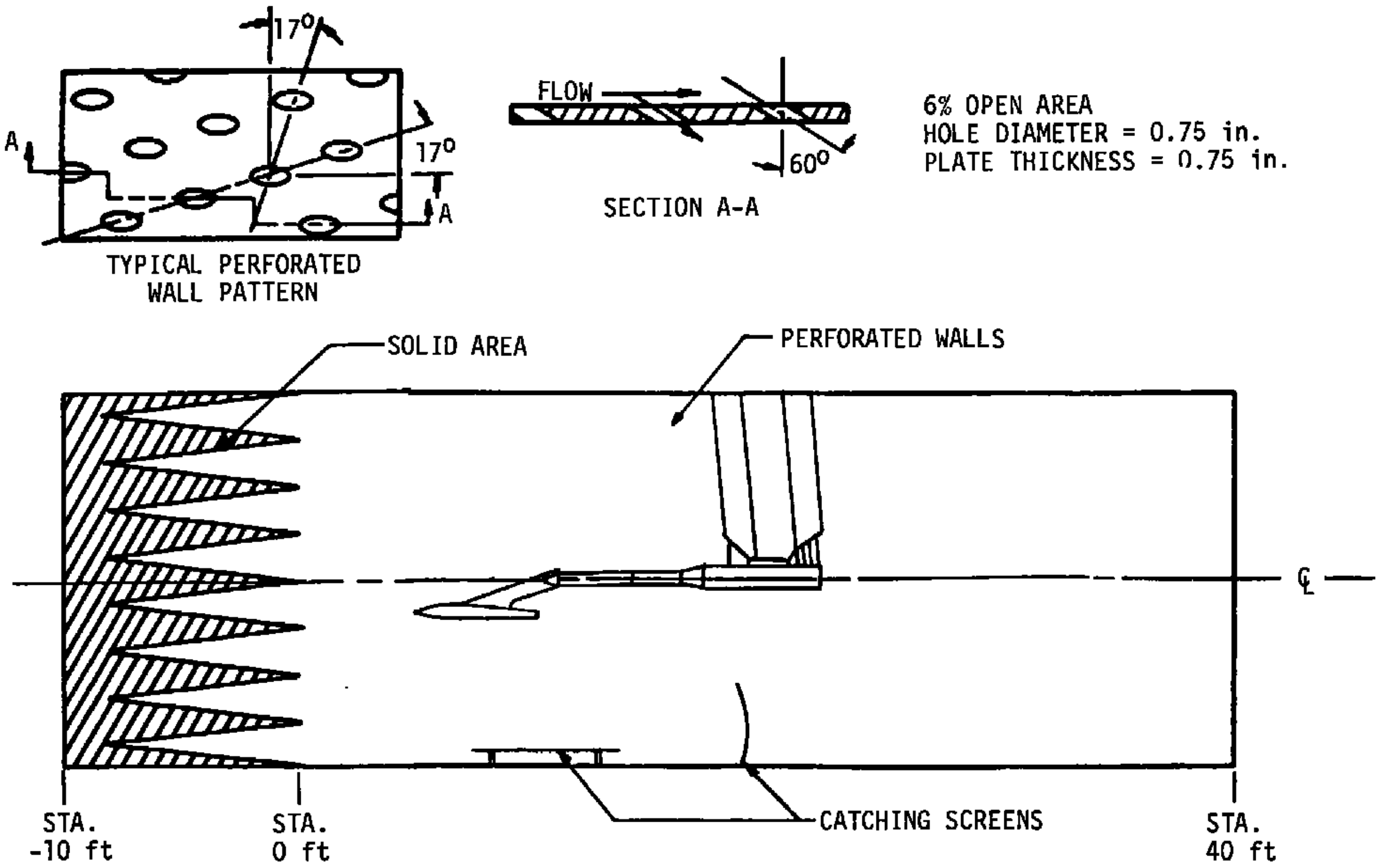


c. Reflection plane mount
Figure 1. Concluded.



a. Strut mount

Figure 2. Typical Tunnel 16T dynamic drop test installations.



b. Sting-strut combination mounting
Figure 2. Concluded.

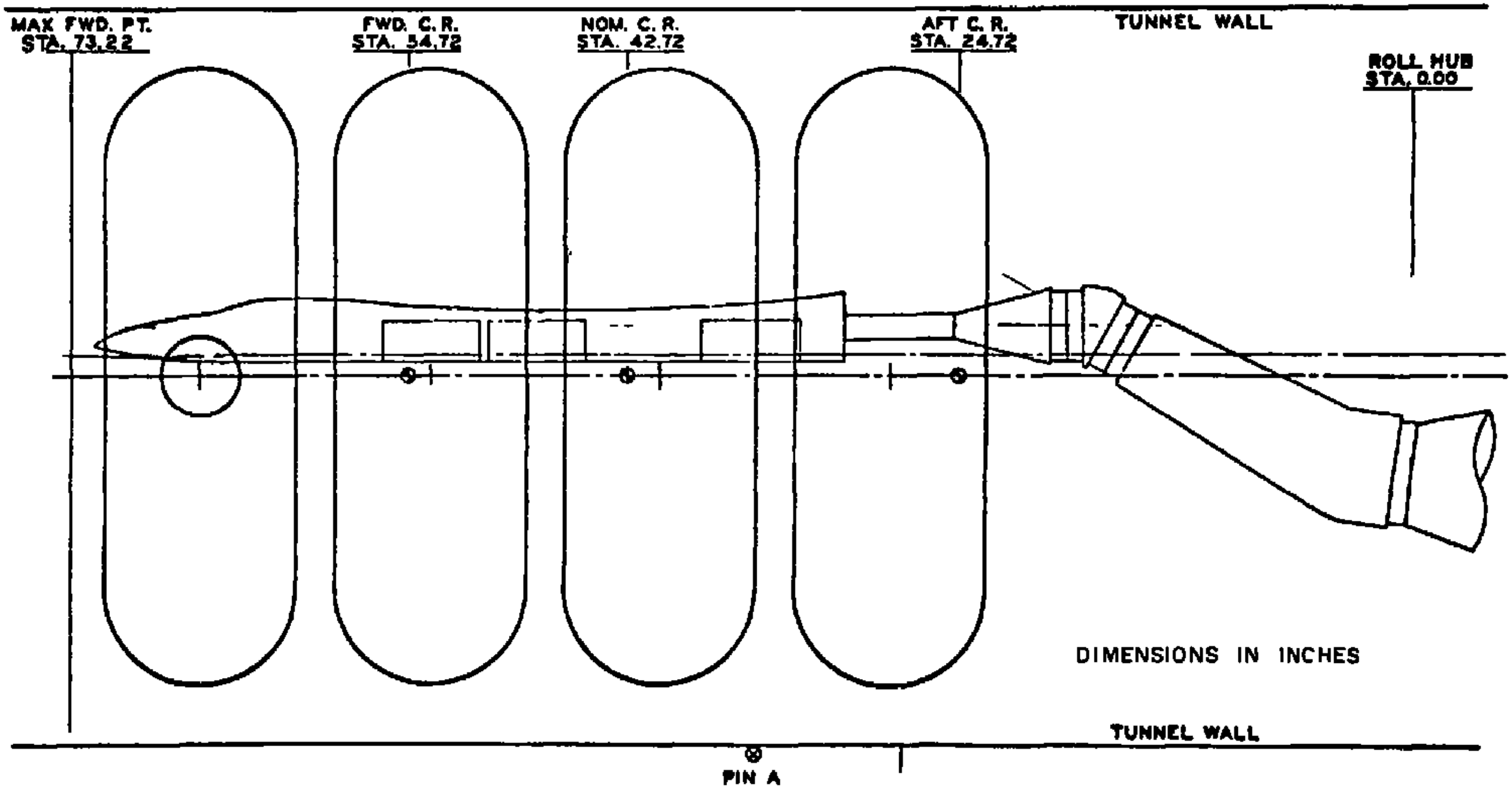
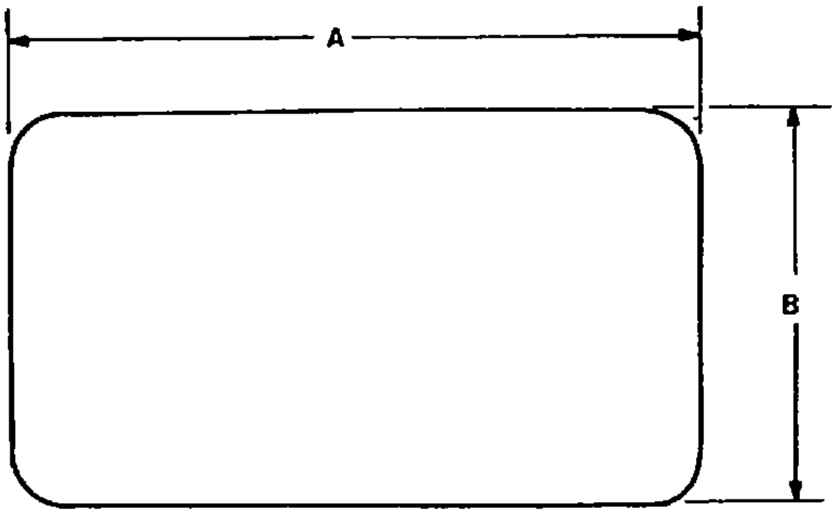


Figure 3. Typical Tunnel A dynamic drop test installation.



TUNNEL	LENS	A (inches)	B (inches)
4T	5.7 mm	42	32
4T	.10.0 mm	24	18
16T	5.9 mm	165	124
16T	10.0 mm	97	73
A	Schlieren	34 Diam	–
A	25.0 mm	21	16
A	50.0 mm	6	4

Figure 4. Data camera fields of view at the tunnel centerline.

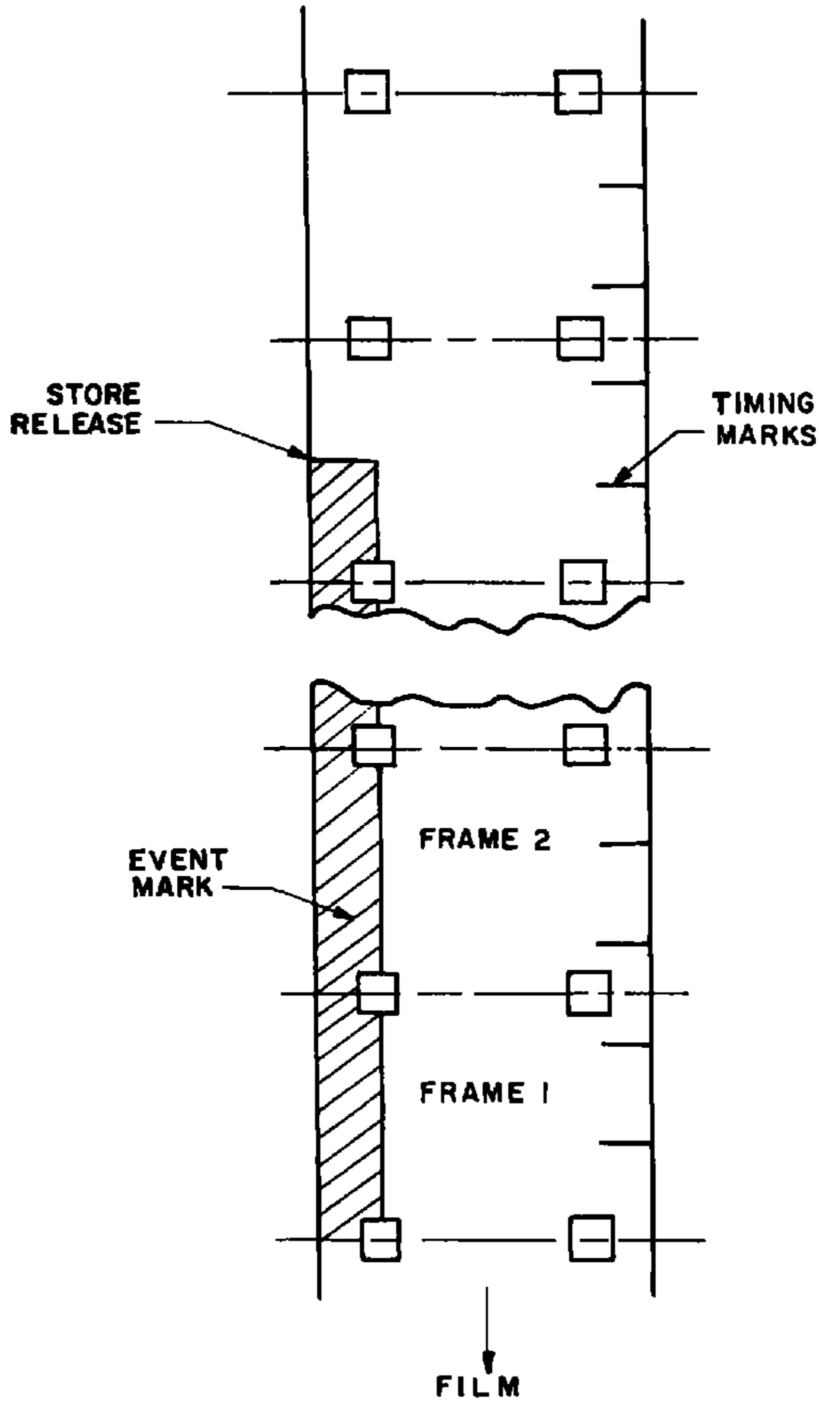


Figure 5. Sketch of film defining timing marks and event mark.

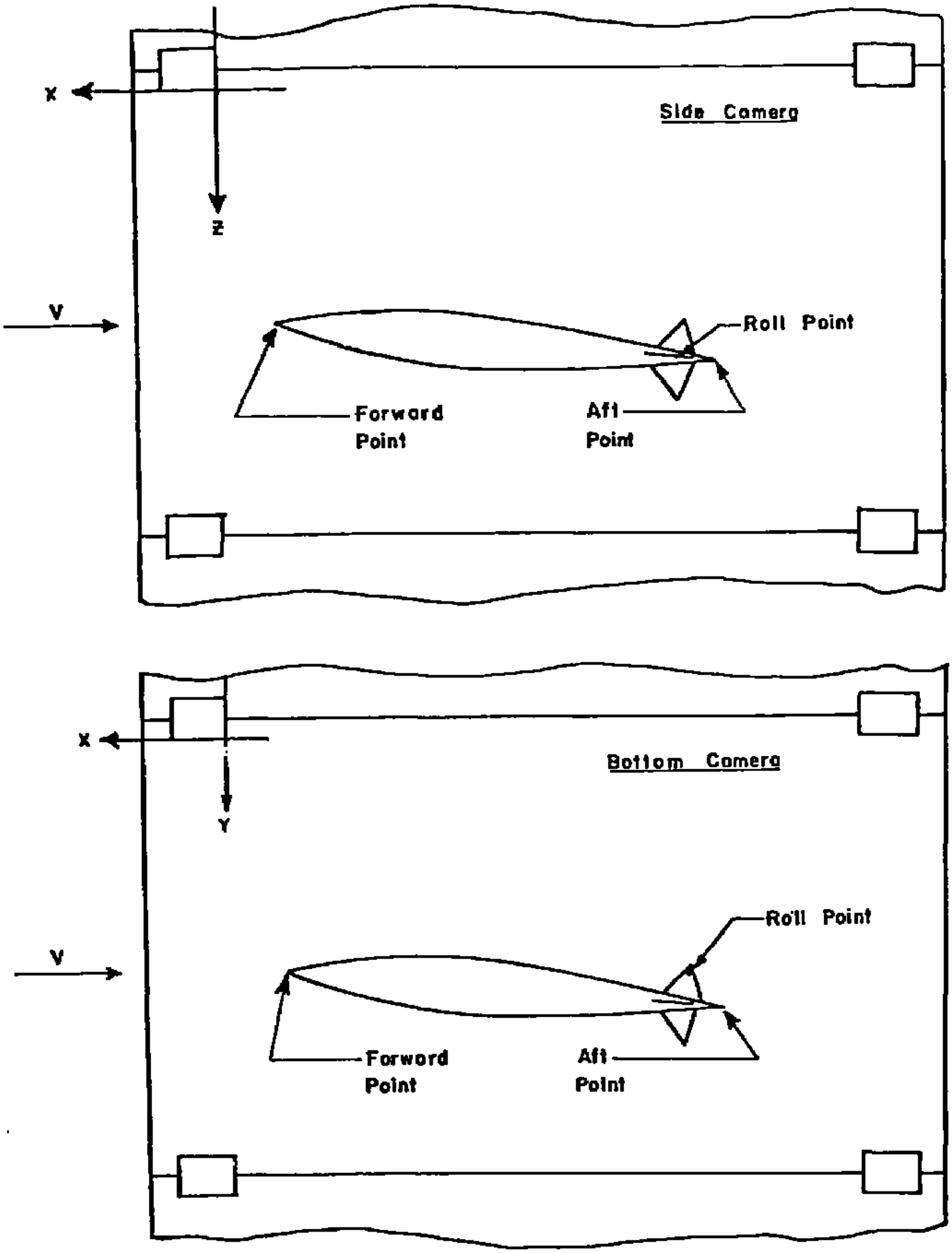
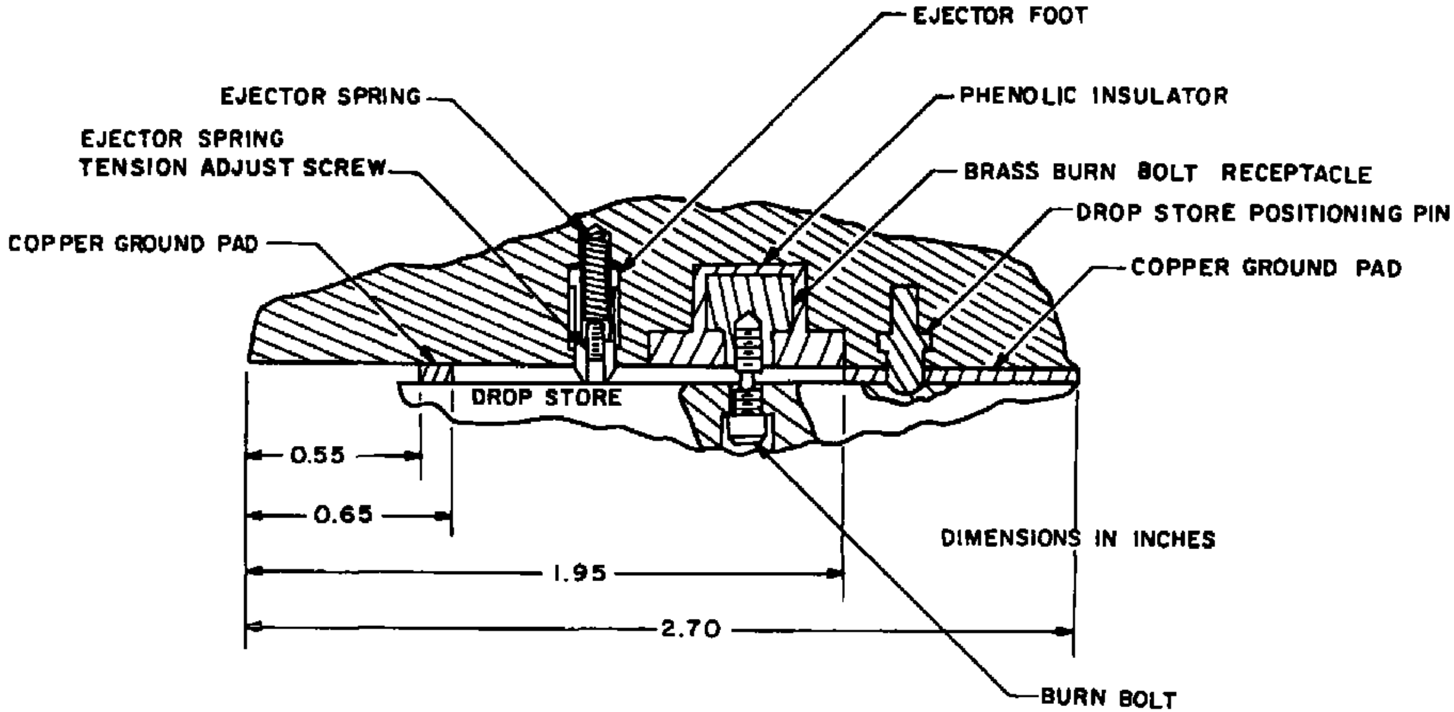
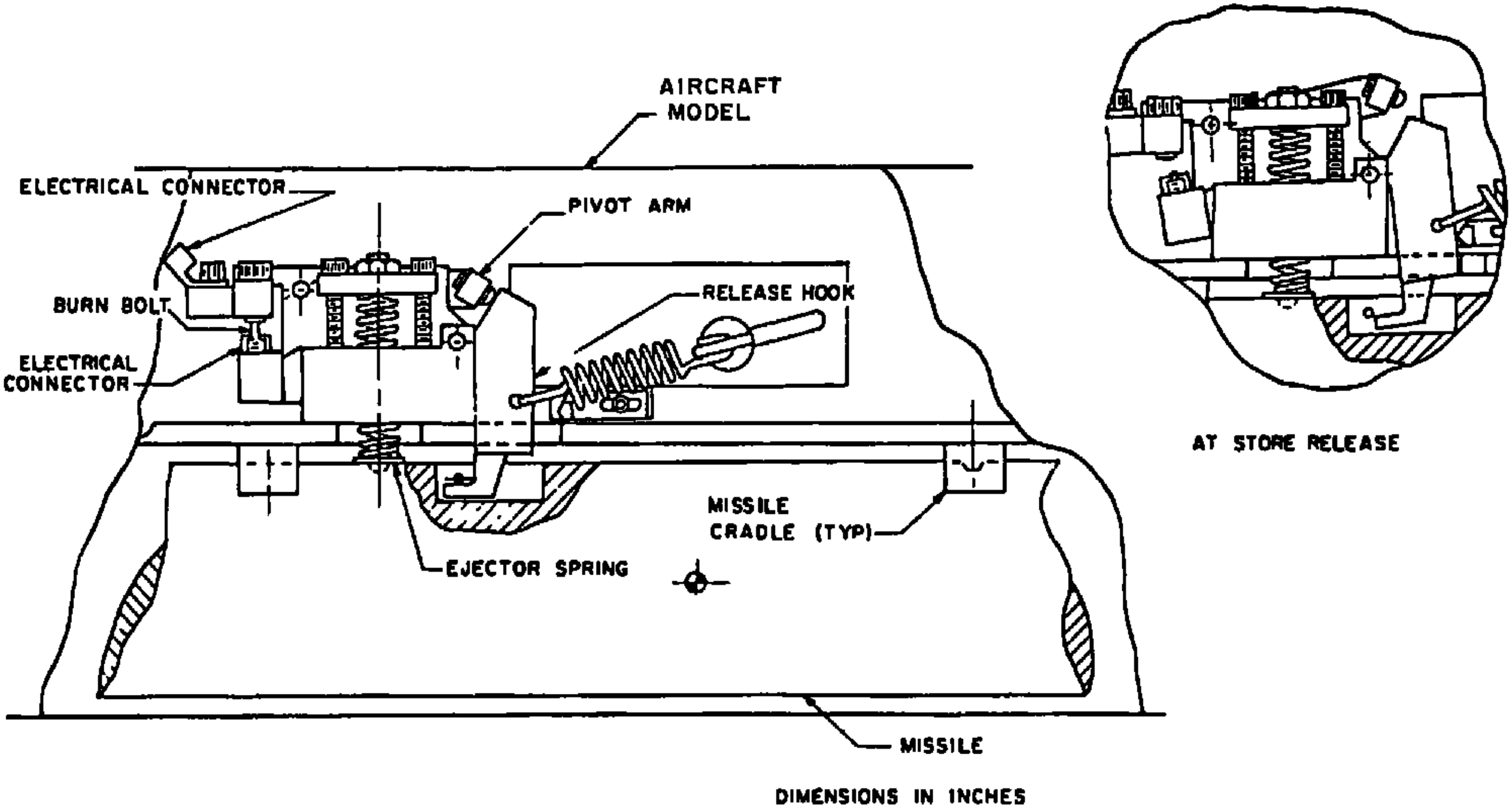


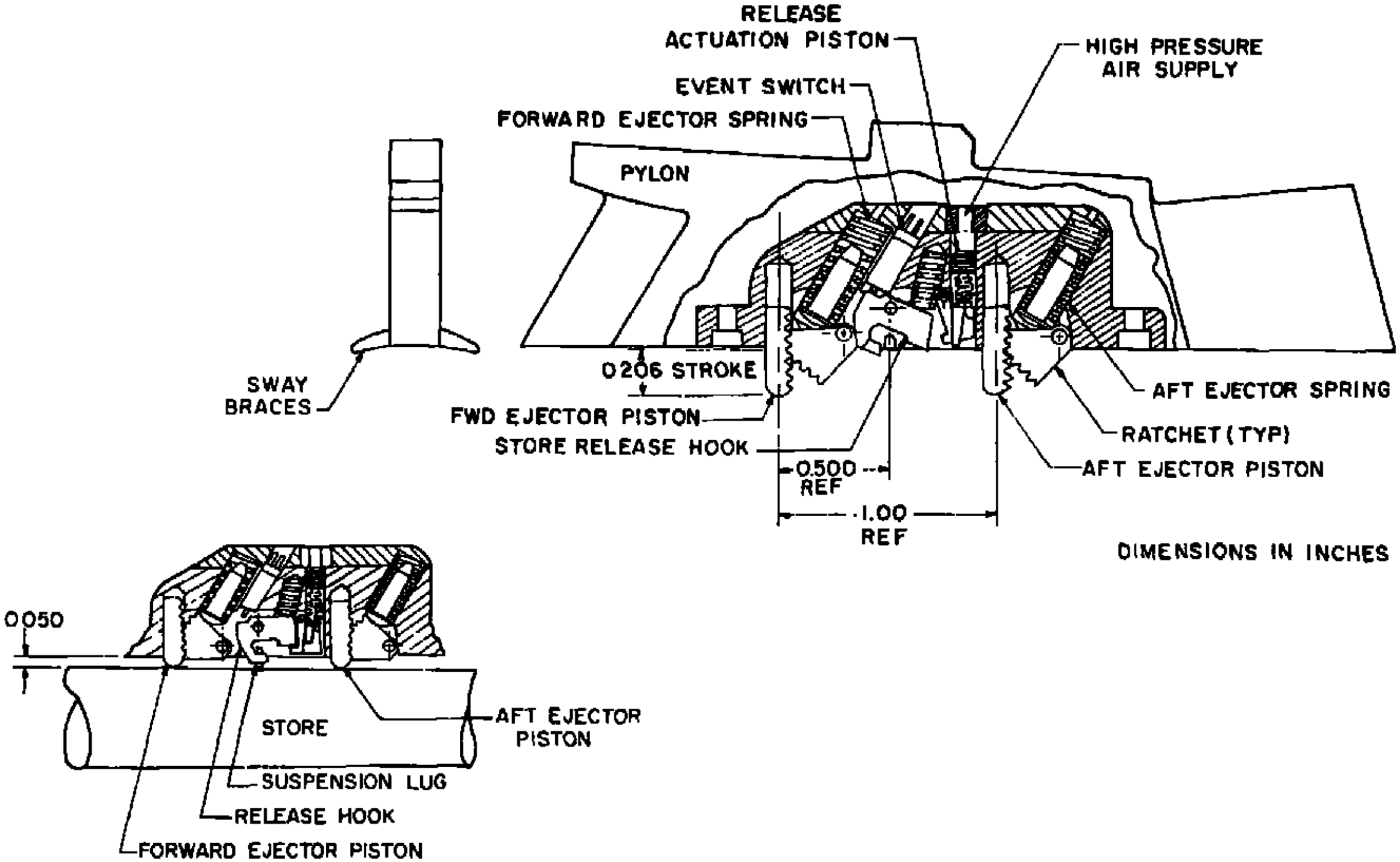
Figure 6. Store reference points and film plane definition.



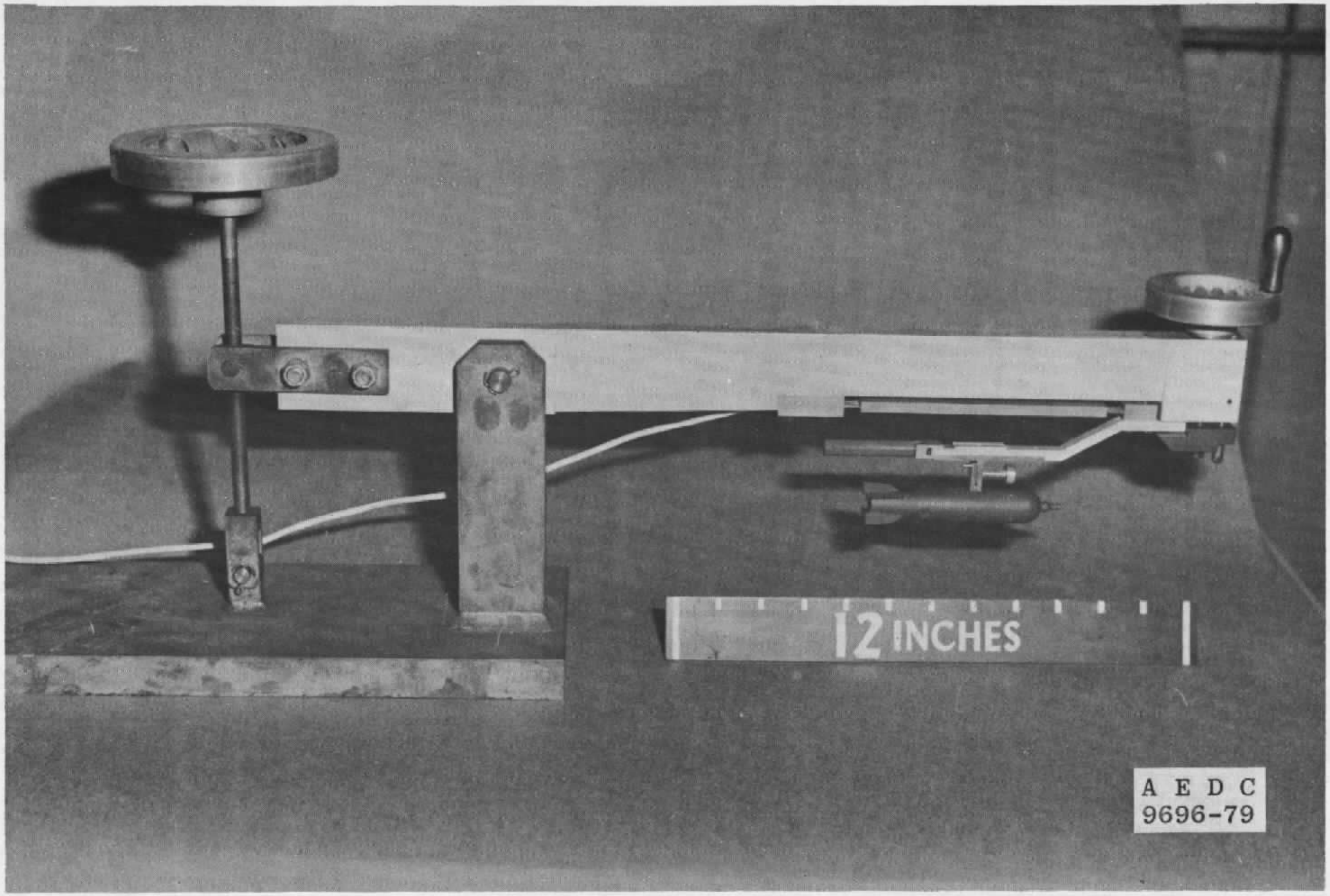
a. Direct burn bolt release
Figure 7. Examples of release mechanisms.



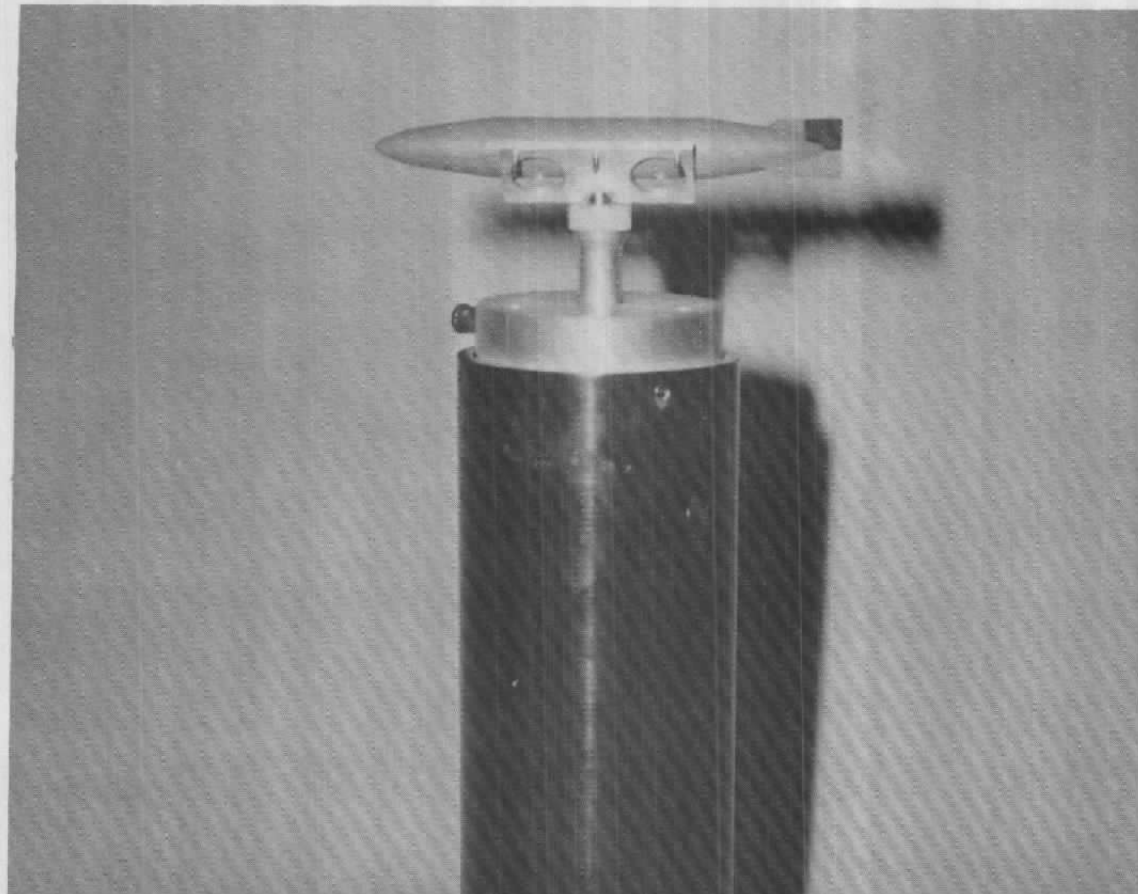
b. Burn bolt-actuated hook release
Figure 7. Continued.



c. Air-actuated hook release
Figure 7. Concluded.



a. Center-of-gravity determination mechanism
Figure 8. Drop model calibration equipment.



b. Moment-of-inertia determination mechanism
Figure 8. Concluded.

Table 1. Typical Tabulated Data Output Formats
a. Flight and Pylon Axes

DATE, 11- -7 PROJECT NO. P C-
ARO, INC.
AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
PROPULSION WIND TUNNEL
ARNOLD AIR FORCE STATION, TENNESSEE

TEST	RUN	M	PT	P	Q	TT	T	V	RE	H	QA	SCALE	FRAMES USED	TRANSONIC 4T
TC-	10	0.952	685.9	352.7	242.9	549.2	464.9	1005.8	1.408	0.0	1339.4	0.050	61	

ALPHA	BETA	CONFIG	TRAJ	MODEL SCALE PARAMETERS	WTM	IYYM	XCGM	YCGM	ZCGM	FEM	MEYM	IERROR
1.84	0.0	100	3		1.614	10.140	3.800	0.0	0.827	0.0	0.0	-1.46

A/C	STORE	IP	FULL SCALE PRMTS L	WT	IYY	XCG	YCG	ZCG	FE	MEY	ISIM
F-		-3.00	12.92	3560.0	1903.1	6.333	0.0	1.378	0.0	0.0	1931.0

STORE NO
66

POINT	TIME	X	Y	Z	PSI	THETA	PHI	XP	YP	ZP	DPSI	DTHETA	DPHI
1	-0.0087	0.0	0.0	0.0	0.19	-2.01	2.57	0.0	0.0	0.0	0.19	-0.85	2.58
2	0.0024	0.09	-0.02	-0.09	0.25	-2.15	3.18	0.09	-0.02	-0.09	0.25	-0.99	3.19
3	0.0135	0.02	-0.01	0.02	0.49	-2.11	-0.58	0.02	-0.01	0.02	0.49	-0.95	-0.57
4	0.0246	0.03	0.03	0.02	0.43	-2.37	0.72	0.03	0.03	0.02	0.43	-1.21	0.73
5	0.0357	0.05	-0.01	-0.04	0.18	-2.27	3.40	0.05	-0.01	-0.04	0.18	-1.11	3.40
6	0.0468	0.12	0.03	-0.08	0.57	-2.49	4.09	0.11	0.03	-0.09	0.57	-1.33	4.10
7	0.0579	0.08	0.00	0.06	0.62	-1.84	-2.36	0.08	0.00	0.05	0.62	-0.68	-2.34
8	0.0691	0.08	-0.01	0.08	0.51	-2.08	-2.75	0.08	-0.01	0.08	0.50	-0.92	-2.74
9	0.0802	0.05	-0.04	-0.02	0.49	-2.64	2.64	0.05	-0.04	-0.02	0.49	-1.48	2.65
10	0.0913	0.03	0.03	-0.06	0.44	-2.77	5.97	0.03	0.03	-0.06	0.44	-1.61	5.98
11	0.1024	-0.01	0.04	0.01	0.31	-2.82	3.13	-0.01	0.04	0.01	0.31	-1.66	3.14
12	0.1135	0.01	-0.02	0.04	0.25	-3.44	2.30	0.01	-0.02	0.04	0.25	-2.28	2.30
13	0.1246	-0.03	-0.01	0.07	0.56	-3.78	3.11	-0.03	-0.01	0.07	0.56	-2.62	3.12
14	0.1357	-0.06	-0.04	0.17	0.76	-4.10	0.99	-0.05	-0.04	0.17	0.76	-2.94	1.01
15	0.1468	-0.11	-0.06	0.12	0.66	-4.40	3.57	-0.11	-0.06	0.12	0.66	-3.24	3.59
16	0.1579	-0.22	-0.00	0.22	0.51	-4.77	3.89	-0.21	-0.00	0.23	0.51	-3.61	3.90
17	0.1690	-0.25	-0.01	0.13	0.12	-5.20	9.84	-0.25	-0.01	0.13	0.12	-4.04	9.85
18	0.1801	-0.29	0.01	0.22	0.15	-5.57	10.49	-0.29	0.01	0.23	0.15	-4.41	10.49
19	0.1913	-0.40	0.04	0.22	0.62	-6.42	13.66	-0.39	0.04	0.23	0.61	-5.26	13.67
20	0.2024	-0.44	-0.01	0.51	0.64	-7.00	4.82	-0.43	-0.01	0.52	0.64	-5.84	4.83
21	0.2135	-0.53	0.04	0.53	0.51	-7.61	10.76	-0.52	0.04	0.54	0.51	-6.45	10.77
22	0.2246	-0.63	0.07	0.52	0.40	-8.18	12.36	-0.62	0.07	0.53	0.40	-7.02	12.37
23	0.2357	-0.70	0.05	0.66	0.15	-9.59	9.15	-0.69	0.05	0.68	0.15	-8.43	9.16
24	0.2468	-0.79	-0.01	0.94	0.59	-10.04	1.51	-0.77	-0.01	0.95	0.58	-8.88	1.52
25	0.2579	-0.94	-0.03	1.08	1.30	-10.82	-1.38	-0.92	-0.03	1.10	1.30	-9.66	-1.36
26	0.2690	-1.04	0.09	1.19	1.29	-12.05	3.74	-1.02	0.09	1.21	1.29	-10.89	3.77
27	0.2801	-1.19	0.13	1.23	0.94	-13.19	6.59	-1.17	0.13	1.25	0.94	-12.03	6.61
28	0.2912	-1.25	0.17	1.45	0.73	-13.78	7.54	-1.22	0.17	1.47	0.73	-12.62	7.56
29	0.3023	-1.42	0.19	1.57	1.09	-15.23	8.59	-1.39	0.19	1.59	1.08	-14.07	8.61
30	0.3134	-1.55	0.15	1.79	1.15	-16.51	5.29	-1.52	0.15	1.82	1.15	-15.35	5.31
31	0.3246	-1.65	0.18	1.86	0.97	-17.64	11.10	-1.61	0.18	1.89	0.96	-16.48	11.12
32	0.3357	-1.79	0.21	2.07	0.64	-18.96	12.20	-1.75	0.21	2.11	0.63	-17.80	12.21
33	0.3468	-2.00	0.23	2.36	0.54	-20.39	9.08	-1.95	0.23	2.40	0.54	-19.23	9.09

Table 1. Concluded
b. Nose and Tail Coordinates

DATE. 11- -7 PROJECT NO. P C-
ARO, INC.
AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
PROPULSION WIND TUNNEL
ARNOLD AIR FORCE STATION, TENNESSEE

TEST	RUN	M	PT	P	Q	TT	T	V	RE	M	QA	SCALE	FRAMES USED	TRANSONIC 4T
TC-	10	0.952	685.9	382.9	242.9	549.2	464.9	1005.8	1.408	0.0	1339.4	0.050	61	

ALPHA	BETA	CONFIG	TRAJ	MODEL SCALE PARAMETERS	WTM	IYYM	XCGM	YCGM	ZCGM	FEM	MEYM	IERROR
1.84	0.0	100	3		1.614	10.140	3.800	0.0	0.827	0.0	0.0	-1.46

A/C	STORE	IP	FULL SCALE PRMTS	L	WT	IYY	XCG	YCG	ZCG	FE	MEY	ISIM
F-		-3.00		12.92	3560.0	1903.1	6.333	0.0	1.378	0.0	0.0	1931.0

STORE NO
66

POINT	TIME	XPN	XPT	YPN	YPT	ZPN	ZPT	XP	YP	ZP	DNU	DETA	DOMEGA
1	-0.0087	6.31	-6.60	-0.04	-0.08	1.47	1.28	0.0	0.0	0.0	-0.85	0.19	2.58
2	0.0024	6.40	-6.52	-0.07	-0.12	1.39	1.17	0.09	-0.02	-0.09	-0.99	0.25	3.10
3	0.0135	6.33	-6.59	0.06	-0.05	1.50	1.29	0.02	-0.01	0.02	-0.95	0.49	-0.56
4	0.0246	6.33	-6.58	0.06	-0.03	1.53	1.26	0.03	0.03	0.02	-1.21	0.43	0.74
5	0.0357	6.35	-6.56	-0.07	-0.11	1.46	1.20	0.05	-0.01	-0.04	-1.11	0.18	3.41
6	0.0468	6.41	-6.50	-0.01	-0.14	1.43	1.13	0.11	0.03	-0.09	-1.33	0.57	4.11
7	0.0579	6.39	-6.52	0.13	-0.01	1.51	1.35	0.08	0.00	0.05	-0.68	0.62	-2.34
8	0.0691	6.39	-6.52	0.11	-0.01	1.56	1.35	0.08	-0.01	0.08	-0.92	0.50	-2.73
9	0.0802	6.34	-6.57	-0.05	-0.16	1.52	1.19	0.05	-0.04	-0.07	-1.48	0.49	2.66
10	0.0913	6.32	-6.59	-0.06	-0.16	1.49	1.12	0.03	0.03	-0.06	-1.61	0.44	5.98
11	0.1024	6.28	-6.63	-0.00	-0.07	1.57	1.20	-0.01	0.04	0.01	-1.66	0.31	3.14
12	0.1135	6.28	-6.62	-0.05	-0.11	1.67	1.15	0.01	-0.02	0.04	-2.28	0.25	2.31
13	0.1246	6.24	-6.66	-0.03	-0.15	1.73	1.15	-0.03	-0.01	0.07	-2.62	0.56	3.15
14	0.1357	6.20	-6.70	0.02	-0.15	1.87	1.21	-0.05	-0.04	0.17	-2.94	0.76	1.05
15	0.1468	6.14	-6.76	-0.08	-0.23	1.85	1.12	-0.11	-0.06	0.12	-3.24	0.66	3.42
16	0.1579	6.02	-6.87	-0.04	-0.16	2.00	1.19	-0.21	-0.00	0.23	-3.61	0.51	3.94
17	0.1690	5.97	-6.91	-0.23	-0.26	1.94	1.03	-0.25	-0.01	0.13	-4.04	0.12	9.85
18	0.1801	5.92	-6.96	-0.22	-0.25	2.07	1.07	-0.29	0.01	0.23	-4.41	0.15	10.50
19	0.1913	5.79	-7.07	-0.22	-0.35	2.14	0.96	-0.39	0.04	0.23	-5.26	0.61	13.77
20	0.2024	5.73	-7.11	-0.06	-0.20	2.53	1.21	-0.43	-0.01	0.52	-5.84	0.64	4.90
21	0.2135	5.62	-7.21	-0.16	-0.28	2.60	1.15	-0.52	0.04	0.54	-6.45	0.51	10.92
22	0.2246	5.50	-7.32	-0.18	-0.27	2.64	1.06	-0.62	0.07	0.53	-7.02	0.39	12.42
23	0.2357	5.38	-7.40	-0.15	-0.18	2.95	1.06	-0.69	0.05	0.68	-8.43	0.15	9.18
24	0.2468	5.28	-7.49	0.02	-0.11	3.29	1.30	-0.77	-0.01	0.95	-8.88	0.59	1.61
25	0.2579	5.09	-7.64	0.14	-0.15	3.52	1.35	-0.92	-0.03	1.10	-9.66	1.28	-1.14
26	0.2690	4.94	-7.74	0.13	-0.16	3.76	1.32	-1.02	0.09	1.21	-10.89	1.27	4.01
27	0.2801	4.74	-7.89	0.07	-0.13	3.91	1.22	-1.17	0.13	1.25	-12.03	0.92	6.80
28	0.2912	4.67	-7.94	0.06	-0.10	4.19	1.37	-1.22	0.17	1.47	-12.62	0.71	7.72
29	0.3023	4.42	-8.10	0.09	-0.14	4.46	1.31	-1.39	0.19	1.59	-14.07	1.05	8.87
30	0.3134	4.23	-8.22	0.14	-0.11	4.82	1.40	-1.52	0.15	1.82	-15.35	1.11	5.61
31	0.3246	4.08	-8.30	0.01	-0.20	4.99	1.32	-1.61	0.18	1.89	-16.48	0.92	11.39
32	0.3357	3.87	-8.43	-0.02	-0.15	5.33	1.38	-1.75	0.21	2.11	-17.80	0.60	12.40
33	0.3468	3.58	-8.61	0.06	-0.05	5.78	1.52	-1.95	0.23	2.40	-19.23	0.51	9.27

NOMENCLATURE

A. DYNAMIC DROP TABULATED DATA

TEST DATA IDENTIFICATION AND WIND TUNNEL PARAMETERS

DATE	Calendar time at which data were recorded
M	Wind tunnel free-stream Mach number
P, PT	Wind tunnel free-stream static and total pressures, respectively, psfa
POINT	Sequential indexing number for referencing data obtained during one trajectory; indexes each time a new set of data inputs is obtained
PROJECT	Alphanumeric notation for referencing a specific test project
Q	Wind tunnel free-stream dynamic pressure, psf
RE	Wind tunnel free-stream unit Reynolds number, millions per foot
RUN	Sequential indexing number for referencing data - a constant throughout each trajectory
T, TT	Wind tunnel free-stream static and total temperatures, respectively, °R
TEST	Alphanumeric notation for referencing a specific test program in a specific test unit
TRAJ	Configuration indexing number used to correlate data with the test log
V	Wind tunnel free-stream velocity, ft/sec

AIRCRAFT-RELATED PARAMETERS

A/C	Aircraft designation

ALPHA,BETA	Aircraft-model angle of attack and sideslip angle, respectively, deg
CONFIG	Aircraft store loading designation
IP,IY	Pitch and yaw incidence angles of the store longitudinal axis at carriage with respect to the aircraft longitudinal axis, positive nose up and nose to the right, respectively, as seen by pilot, deg
SCALE, λ	Aircraft model scale factor

STORE-RELATED PARAMETERS

IERROR	Percent error in the simulated full-scale moment of inertia about the store Y_B axis, (IYY - ISIM) (100)/IYY
ISIM	Simulated full-scale moment of inertia about the store Y_B axis, (IYYM) $(2.1584 - 10^{-4})$ (QA)/(λ^4Q), slug-ft^2
IYY	Actual full-scale moment of inertia about the store Y_B axis, slug-ft^2
IYYM	Store model moment of inertia about the Y_B axis, lb-in.^{2}
L	Store length, ft, full scale
STORE	Store model designation
STORE NO	Numerical identification of drop model
WT	Full-scale store weight, lb
WTM	Store model weight, lb
XCG	Axial distance from the store nose to the cg location, ft, full scale
XCGM	Axial distance from the store nose to the cg location, in., model scale
YCG,ZCG	Lateral and vertical distances from the store reference axis to the cg location, positive in the positive Y_B and Z_B directions, respectively, ft, full scale

YCGM,ZCGM — Lateral and vertical distances from the store model reference axis to the cg location, positive in the positive Y_B and Z_B directions, respectively, in.

TRAJECTORY SIMULATION PARAMETERS

H — Simulated pressure altitude, kft

QA — Simulated full-scale dynamic pressure, psf

TIME — Cumulative time for the trajectory, seconds of full-scale flight time following release of store

EJECTOR SIMULATION PARAMETERS

FE,FEM — Full-scale and model-scale ejector force, respectively, lb

MEY — Full-scale moment about the store cg imparted by the ejector, ft-lb

MEYM — Model-scale moment about the store model cg imparted by the model ejector, in.-lb

MISCELLANEOUS AND TEST-PECULIAR PARAMETERS

FRAMES USED — Number of frames of data film used during the calculation of the trajectory

B. AXIS SYSTEM DEFINITIONS

STORE BODY-AXIS SYSTEM

Coordinate Directions

X_B — Parallel to the store longitudinal axis, positive is upstream at the carriage position

Y_B — Perpendicular to X_B and Z_B directions, positive is to the right looking upstream when the store is at zero yaw and roll angles

Z_B — Perpendicular to the X_B direction and parallel to the X_I-Z_I plane when the store is at zero yaw and roll angles, positive is downward as seen by the pilot when the store is at zero pitch and roll angles

Origin

The store body-axis system origin is coincident with the store cg at all times. The X_B, Y_B, and Z_B coordinate axes rotate with the store in pitch, yaw, and roll so that mass moments of inertia about the three axes are not time-varying quantities.

INERTIAL-AXIS SYSTEM DEFINITIONS

Coordinate Directions

X_I — Parallel to the aircraft flight path direction at store release, positive is forward as seen by the pilot

Y_I — Perpendicular to the X_I and Z_I direction, positive is to the right as seen by the pilot

Z_I — Parallel to the aircraft plane of symmetry and perpendicular to the aircraft flight path direction at store release, positive is downward as seen by the pilot

Origin

The inertial axis system origin is coincident with the store cg at release and translates along the initial aircraft flight path direction at the free-stream velocity. The coordinate axes do not rotate with respect to the initial aircraft flight path direction.

Attitudes (Pitch, Yaw, Roll Sequence)

ν_I,NUI — Angle between the projection of the store longitudinal axis in the X_I-Z_I plane and the X_I axis, positive for the store nose raised as seen by the pilot, deg

η_I,ETAI — Angle between the store longitudinal axis and its projection in the X_I-Z_I plane, positive when the store nose is to the right as seen by the pilot, deg

ω_I,OMEGAI — Angle between the store vertical (Z_B) axis and the intersection of the Y_B-Z_B and X_I-Z_I planes, positive for clockwise rotation when looking upstream, deg

FLIGHT-AXIS SYSTEM DEFINITIONS

Coordinate Directions

X_F — Parallel to the current aircraft flight path direction, positive forward as seen by the pilot

Y_F — Perpendicular to the X_F and Z_F directions, positive to the right as seen by the pilot

Z_F — Parallel to the aircraft plane of symmetry and perpendicular to the current aircraft flight path direction, positive downward as seen by the pilot

Origin

The flight-axis system origin is coincident with the store cg at the carriage position. The origin is fixed with respect to the aircraft and thus translates along the current aircraft flight path at the free-stream velocity. The coordinate axes rotate to maintain alignment of the X_F axis with the current aircraft flight path direction.

Positions

X — Separation distance of the store cg from the flight-axis system origin in the X_F direction, ft, full scale

Y — Separation distance of the store cg from the flight-axis system origin in the Y_F direction, ft, full scale

Z — Separation distance of the store cg from the flight-axis system origin in the Z_F direction, ft, full scale

Attitudes (Yaw, Pitch, Roll Sequence)

θ,THA — Angle between the store longitudinal axis and its projection in the X_F-Y_F plane, positive when the store nose is raised as seen by the pilot, deg

ϕ,PHI	Angle between the store lateral (Y_B) axis and the intersection of the Y_B-Z_B and X_F-Y_F planes, positive for clockwise rotation when looking upstream, deg
ψ,PSI	Angle between the projection of the store longitudinal axis in the X_F-Y_F plane and X_F axis, positive when the store nose is to the right as seen by the pilot, deg

Attitudes (Pitch, Yaw, Roll Sequence)

η,ETA	Angle between the store longitudinal axis and its projection in the X_I-Z_I plane, positive when the store nose is to the right as seen by the pilot, deg
ν,NU	Angle between the projection of the store longitudinal axis in the X_I-Z_I plane and the X_I axis, positive for the store nose raised as seen by the pilot, deg
ω,OMEGA	Angle between the store vertical (Z_B) axis and the intersection of the Y_B-Z_B and X_I-Z_I planes, positive for clockwise rotation when looking upstream, deg

PYLON-AXIS SYSTEM DEFINITIONS

Coordinate Directions

X_P	Parallel to the store longitudinal axis at the carriage position and at constant angular orientation with respect to the current aircraft flight path direction, positive is forward as seen by the pilot
Y_P	Perpendicular to the X_P direction and parallel to the X_F-Y_F plane, positive is to the right as seen by the pilot
Z_P	Perpendicular to the X_P and Y_P directions, positive is downward as seen by the pilot

Origin

The pylon-axis system origin is coincident with the flight-axis system origin and the store cg at the carriage position. It is fixed with respect to the aircraft and thus translates along the current aircraft flight path at the free-stream velocity. The coordinate axes rotate to maintain constant angular orientation with respect to the current aircraft flight path direction.

$\Delta\phi$,DPHI	Angle between the store lateral (Y_B) axis and the intersection of the Y_B-Z_B and X_P-Y_P planes, positive for clockwise rotation when looking upstream, deg

Attitudes (Pitch, Yaw, Roll Sequence)

$\Delta\eta$,DETA	Angle between the store longitudinal axis and its projection in the X_P-Z_P plane, positive when the store nose is to the right as seen by the pilot, deg
$\Delta\nu$,DNU	Angle between the projection of the store longitudinal axis in the X_P-Z_P plane and the X_P axis, positive for the store nose raised as seen by the pilot, deg
$\Delta\omega$,DOMEGA	Angle between the store vertical (Z_B) axis and the intersection of the Y_B-Z_P planes, positive for clockwise rotation when looking upstream, deg

NOSE, TAIL COORDINATE PARAMETERS

XPi,YPi,ZPi	Location of the store nose (i = N) or tail (i = T) in the pylon-axis system X_P, Y_P, and Z_P directions; ft, full scale measured from the carriage position of the store cg (referenced to the rack length)

Positions

XP	Separation distance of the store cg with respect to the pylon-axis system origin in the X_P direction, ft, full scale
YP	Separation distance of the store cg with respect to the pylon-axis system origin in the Y_P direction, ft, full scale
ZP	Separation distance of the store cg with respect to the pylon-axis system origin in the Z_P direction, ft, full scale